Advanced Source Deconvolution Methods for Compton Telescopes

Completed Technology Project (2017 - 2018)

Project Introduction

The next generation of space telescopes utilizing Compton scattering for astrophysical observations is destined to one day unravel the mysteries behind Galactic nucleosynthesis, to determine the origin of the positron annihilation excess near the Galactic center, and to uncover the hidden emission mechanisms behind gamma-ray bursts. Besides astrophysics, Compton telescopes are establishing themselves in heliophysics, planetary sciences, medical imaging, accelerator physics, and environmental monitoring. Since the COMPTEL days, great advances in the achievable energy and position resolution were possible, creating an extremely vast, but also extremely sparsely sampled data space. Unfortunately, the optimum way to analyze the data from the next generation of Compton telescopes has not yet been found, which can retrieve all source parameters (location, spectrum, polarization, flux) and achieves the best possible resolution and sensitivity at the same time. This is especially important for all sciences objectives looking at the inner Galaxy: the large amount of expected sources, the high background (internal and Galactic diffuse emission), and the limited angular resolution, make it the most taxing case for data analysis. In general, two key challenges exist: First, what are the best data space representations to answer the specific science questions? Second, what is the best way to deconvolve the data to fully retrieve the source parameters? For modern Compton telescopes, the existing data space representations can either correctly reconstruct the absolute flux (binned mode) or achieve the best possible resolution (list-mode), both together were not possible up to now. Here we propose to develop a two-stage hybrid reconstruction method which combines the best aspects of both. Using a proof-of-concept implementation we can for the first time show that it is possible to alternate during each deconvolution step between a binned-mode approach to get the flux right and a list-mode approach to get the best angular resolution, to get achieve both at the same time! The second open question concerns the best deconvolution algorithm. For example, several algorithms have been investigated for the famous COMPTEL 26Al map which resulted in significantly different images. There is no clear answer as to which approach provides the most accurate result, largely due to the fact that detailed simulations to test and verify the approaches and their limitations were not possible at that time. This has changed, and therefore we propose to evaluate several deconvolution algorithms (e.g. Richardson-Lucy, Maximum-Entropy, MREM, and stochastic origin ensembles) with simulations of typical observations to find the best algorithm for each application and for each stage of the hybrid reconstruction approach. We will adapt, implement, and fully evaluate the hybrid source reconstruction approach as well as the various deconvolution algorithms with simulations of synthetic benchmarks and simulations of key science objectives such as diffuse nuclear line science and continuum science of point sources, as well as with calibrations/observations of the COSI balloon telescope. This proposal for “development of new data analysis methods for future satellite missions” will significantly improve the source deconvolution techniques for

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Organizational Responsibility

Responsible Mission Directorate:

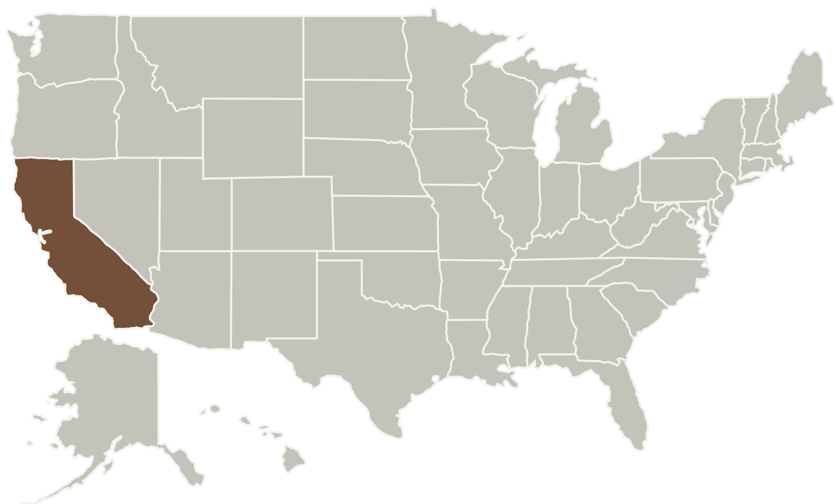
Science Mission Directorate (SMD)

Responsible Program:

Astrophysics Research and Analysis

modern Compton telescopes and will allow unlocking the full potential of envisioned satellite missions using Compton-scatter technology in astrophysics, heliophysics and planetary sciences, and ultimately help them to “discover how the universe works” and to better “understand the sun”. Ultimately it will also benefit ground based applications such as nuclear medicine and environmental monitoring as all developed algorithms will be made publicly available within the open-source Compton telescope analysis framework MEGAlib.

Primary U.S. Work Locations and Key Partners



Primary U.S. Work Locations
California

Project Management

Program Director:
Michael A Garcia

Program Manager:
Dominic J Benford

Principal Investigator:
Andreas Zoglauer

Co-Investigators:
Steven E Boggs
Carolyn Kierans
Cora Basada

Technology Areas

Primary:

- TX02 Flight Computing and Avionics
  └ TX02.1 Avionics Component Technologies
    └ TX02.1.3 High Performance Processors

Target Destination
Outside the Solar System